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TO BE LAUNCHED NO EARLIER THAN NOVEMBER 2, 1965

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NASA TO LAUNCH  
GEODETIC SATELLITE,  
FIRST OF ITS TYPE

The National Aeronautics and Space Administration will launch from Cape Kennedy no earlier than Nov. 2, a new type of Explorer satellite designed exclusively for geodetic studies.

Geodesy is the mathematical determination of the Earth's size, shape, mass, and variations in gravity.

The 385-pound Geodetic Explorer spacecraft, designated GEOS-A, contains five geodetic instrumentation systems to provide simultaneous measurements that scientists require to establish a more precise model of the Earth's gravitational field and to map a world coordinate system relating points on or near the surface to the common center of mass.

Launch vehicle will be NASA's Thrust-Augmented Improved Delta. This will be the first launch for the Improved Delta second stage. Enlarged fuel tanks provide a longer engine burning time than the standard Delta previously used by NASA.

The compact spacecraft (the first of two) was designed and built by John Hopkins University's Applied Physics Laboratory in Howard County, Md.

In recent years the need has increased for more precise geodetic data that can be used both for mapping long distances and for analyzing geophysical problems. Satellite geodesy, together with seismic data and information on heat flow and the behavior of matter under great pressure, will help meet this need.

Examples of the potential scientific values to be derived from satellite geodesy are (1) detecting and measuring long-term lateral and vertical shifting of major land masses and island chains, (2) mapping the density, pressure, and composition of the Earth's interior and generally, increasing mankind's knowledge of the geoid's structure and past history, (3) developing a capability for forecasting major earthquake activity, (4) enhancing the use of satellites for navigational purposes, and (5) improving the positional accuracy of satellite tracking sites and the calibration of tracking equipment.

Without the ability to pinpoint the places at which gravity is measured with respect to a single center-of-Earth coordinate system, local gravity measurements lose their value. Similarly, accurate knowledge of varying gravitational effects on satellites is necessary for the most effective use of satellites in geometrical triangulation surveys.

Existing tracking networks, optical and electronic, form the basis of GEOS-A's experimental work.

The five geodetic measurement systems on GEOS-A consist of (1) a flashing light beacon to be photographed against the background of stars to define the arc of orbit and angular data, (2) corner cube quartz reflectors to pinpoint the satellite's position by reflecting laser beams, (3) three radio transmitters for Doppler-shift determination of the precise orbit, (4) radio range transponder to fix the satellite's position and that of

interrogating ground stations, and (5) range and range-rate transponder to determine the changing range and radial velocity of the satellite.

Simultaneous operation of the five independent and diverse geodetic-tracking systems will permit cross-checking and evaluation of the functioning and accuracies of the different techniques and is expected to enhance the accuracy of each system.

Upon achieving orbit the spacecraft will be designated Explorer XXIX.\* The desired orbit will be inclined 59 degrees to the Equator with the altitude of the spacecraft ranging from about 690 statute miles to about 920 statute miles. The orbital period will be about one hour, 52 minutes.

The United States Geodetic Satellite Program, a coordinated undertaking of NASA, the Department of Defense and the Department of Commerce (Coast and Geodetic Survey), is managed by NASA with overall responsibility assigned to the Physics and Astronomy Division of the Office of Space Science and Applications (OSSA).

The program entails broad international cooperation in ground-based observations and data acquisition and analysis. Integrated networks of ground stations, some mobile, will extend around the globe and from Greenland to Antarctica.

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\* The roman numeral could change if the launch is delayed and another Explorer satellite achieves orbit in the meantime. Explorer satellites received roman numeral designation according to sequence in which they achieve orbit.

All relevant data will be openly available to participants in the program. Results will be made available to the international scientific community.

Principal scientific investigators in the GEOS-A project represent Ohio State University, Columbus; University of California (Los Angeles); Smithsonian Astrophysical Observatory, (SAO) Cambridge, Mass.; NASA Goddard Space Flight Center, Greenbelt, Md.; U. S. Air Force (Cambridge Research Laboratory) (AFCLR) Cambridge, Mass.; U.S. Navy (Bureau of Naval Weapons); United States Coast and Geodetic Survey; and the U. S. Army (Office of Chief of Engineers).

The Goddard Space Flight Center has a major role in the GEOS project before and after launch.

Goddard is responsible for the Delta vehicle system and spacecraft-vehicle integration. Also assigned to Goddard is responsibility for coordination and communications between GEOS project management and the scientific experimenters and other participants.

After orbit is achieved and satellite instrumentation has been turned on, Goddard will be responsible for the project's integrated tracking and control effort. All tracking information, visibility computations, flash sequence control and computations, housekeeping telemetry and data reduction will be accomplished by and/or coordinated by the Operations Control Center at Goddard. The center will prepare daily flashing-light schedules for injection into the satellite's memory system by ground signals from APL.

In-flight optical and radio ranging support to be provided by Goddard includes the already operational NASA Range and Range Rate Stations; Minitrack Optical Tracking Station (MOTS) cameras; the Satellite Tracking and Data Acquisition Network (STADAN); and laser tracking facilities.

The Smithsonian Astrophysical Observatory will support the optical tracking with its worldwide network of Baker-Nunn camera stations.

Additional optical tracking will be provided by camera teams of the Coast and Geodetic Survey, AFCRL and Army Map Service as required.

Radio ranging or tracking systems to be operated for GEOS include the Navy Doppler Tracking Network (TRANET) facilities and the Army Map Service Sequential Collation of Range (SECOR) stations.

The Applied Physics Laboratory, in addition to designing and building the GEOS flight unit, is responsible for engineering services through the launch operation, pre-flight testing, coordination with NASA on the interface between spacecraft and vehicle, and post-launch telemetry support.

Operational role of APL will be to inject flash sequences into the satellite's memory system and verify the performance of that system. Signals will be sent from the APL ground station in Maryland.

BACKGROUND INFORMATION

GEOS-A Scientific Objectives

Implementing the overall objectives of the United States Geodetic Satellite Program, the GEOS-A project is designed primarily to connect continental and local geodetic datums (certain specific areas defined and calibrated for reference purposes) in a one-world datum and to relate all surface datums to the Earth's common center of mass so that positions of selected sites can be determined in a new type of three-dimensional coordinate system with an accuracy of 10 meters (about 33 feet) or better. The three-dimensional coordinate system would originate radially from the Earth's center of mass and have one axis (passing through the center) that coincides with the axis around which the Earth rotates.

Other primary objectives of the program are to (1) map with a high degree of mathematical exactness the structure of the Earth's irregular gravitational field and (2) compare and correlate results from the different instrumented techniques employed simultaneously so that greater accuracy and reliability can be accomplished.

Secondary objectives of GEOS-A include (1) obtaining more accurate knowledge of the locations of isolated islands and sites in the geodetic triangulation networks, (2) improving the accuracy of positional knowledge of satellite tracking sites and the calibration of satellite tracking equipment, and (3) making generally available the geodetic information obtained.

In measuring and mapping the Earth's gravitational field the goal of the project scientists is to determine the structure to an accuracy of five parts in 100 million.

It is only in recent years that pronounced irregularities in the Earth's gravitational field have been detected and that requirements have arisen for more precise knowledge of distances between distant points.

#### Progress Made

The U.S. Coast and Geodetic Survey reports that a decade ago points within the United States were known relative to points in Europe to an accuracy of about one quarter mile, or less. This estimate has now been reduced to 500 feet or less between major continental datums.

Satellite geodesy will allow worldwide positions to be refined to a still higher degree as the globe is measured on a total scale rather than by local increments. The intention of the U.S. Geodetic Satellite Program is to reduce the uncertainty of intercontinental datum ties to about 40 feet.

Some of the first calculations of satellite trajectories, led to a good enough estimate of the gross structure of the gravity field and the shape of the Earth to terminate promptly a number of old controversies.

With satellites as tools, scientists have been able to confirm that the Earth is somewhat pear-shaped and a bit flattened at the poles, that the equator is elliptical instead of circular, and that there are four geodetic bulges over which the pull of gravity is markedly greater than expected.

### Need For New Satellites

The initial geodetic studies based on satellite data actually used satellites designed for other purposes. As the usefulness of this approach was quickly exhausted, it became evident that further progress would require more accurate instruments and carefully selected orbits.

The orbits and instrumentation for an early series of Navy experimental satellites were chosen to provide accurate information on the Earth's gravitational field.

The first all-geodetic satellite, ANNA, sponsored by the Army, Navy, Air Force, and NASA was launched in 1962 and provided much detailed information on the highs and lows of the geoid and gravitational field.

More information for the refinement of man's knowledge of the Earth and the gravity field has been provided by NASA's Explorer XXII, launched Oct. 9, 1964 and Explorer XXVII, launched April 29, 1965. Both contain experiments of geodetic value.

### U.S. Geodetic Satellite Program

During the past decade, thanks largely to satellites and highly sensitive instruments, mankind has advanced his knowledge of the shape and gravitational field of the Earth more than he did in the preceding 200 years.

The U.S. Geodetic Satellite Program is aimed at providing the satellites, scientific information, and cooperative framework required to extend and accelerate this advance. The program

is designed to make maximum use of the talents, competence, and capabilities which exist in the nation's universities, private research organizations, industry, and other government agencies.

Direct overall responsibility for the program is assigned to the National Aeronautics and Space Administration with program management exercised by the Physics and Astronomy Programs section of NASA's Office of Space Science and Applications.

The national program is based on recommendations of the Geodetic Satellite Policy Board composed of representatives of NASA, the Department of Defense, and the Department of Commerce. The three agencies are the principal participants.

Three types of spacecraft will be used to obtain information on the geodetic properties of the Earth. Each will have a different orbit.

Two spacecraft supporting the program already are in orbit, Explorers XXII and XXVII. Designed primarily for ionospheric studies, these Beacon Explorers contain two experiments of importance to the geodetic program--corner reflectors to evaluate laser techniques in deriving orbital and geodetic data and Doppler radio transmitters to measure the effect of irregularities in the Earth's gravitational field.

The other two types of spacecraft are designed especially for geodetic work. The GEOS type, described in this press kit, is considered an active spacecraft in that it is fully instrumented,

containing radio and optical equipment that must operate in space. Two GEOS spacecraft are authorized.

The second type is a passive spacecraft, called PAGEOS, resembling Echo I. It will be a single 100-foot diameter inflatable sphere with high visibility. It will not contain any active electronic instrumentation. The last stage of the launch vehicle will contain a simple radio beacon to aid early orbit determination. A PAGEOS launch is expected in 1966.

#### Geodesy--Gravimetric and Geometric

Geodesy refers to the mathematical determination of the Earth's size, shape, mass, and variations in gravity. The U.S. Geodetic Satellite Program involves two kinds of geodesy--gravimetric and geometric.

Gravimetric geodesy is concerned with measuring variations in the Earth's gravitational field.

Geometric geodesy employs the principles of geometry to map the Earth's surface in a three-dimensional reference system.

The GEOS and Beacon Explorers (XXII and XXVII) will support both gravimetric and geometric studies. PAGEOS will support geometric geodesy only.

Main objective of satellite gravimetric geodesy is to establish a model of the gravitational field that includes both the overall pattern (from the Earth's center to deep space) and local characteristics. This calls for determining the distribution of mass within the Earth and fixing the location, magnitude, and intensity of irregularities in the gravitational field.

Ultimate purpose of geometric geodesy is to establish all points on the physical surface of the Earth in a coordinate system originating at the center of mass and with one axis coincident with the rotational axis of the Earth.

Satellites, for the first time in history, have provided geodesy with the means for creating such a reference system with a minimum of hypotheses.

#### Worldwide Interest

Scientists in Finland, France, Sweden, Greece, The Netherlands, Switzerland, United Kingdom, and West Germany have indicated they will participate in the GEOS project and scientists in other countries throughout the world have expressed an interest in cooperating in the program.

The PAGEOS balloon-type satellite particularly is well suited to international cooperation. Geodesists throughout the world, with comparatively small telescopes and field instruments, will be able to observe the satellite easily.

NASA has invited scientists outside the United States to participate in establishing an international observational network for GEOS and PAGEOS.

THE GEOS-A SPACECRAFT

The GEOS-A spacecraft packs most of its 385 pounds into an eight-sided aluminum shell topped with an eight-sided truncated pyramid. The shell is 48 inches wide from one flat side to another and 32 inches high.

Each of the 16 flat side surfaces carries a panel of solar cells. The 4,992 solar cells cover most of the spacecraft's exterior. They convert solar energy to electricity and are designed to provide maximum power output with minimum daily average fluctuations.

Six solar attitude detectors are mounted below the solar cells panel on alternating sides of the shell. The detectors provide information on the satellite's position relative to the Sun.

A 60-foot boom of silver-plated beryllium-copper extends from the top of the satellite to provide gravity-gradient attitude stabilization of the satellite so that the optical beacons and radio antennas point Earthward at all times.

A damper on the end of the boom provides the dumbbell configuration required for stabilizing the satellite by the gravity-gradient method and removes residual oscillations of the satellite after boom extension. The boom can be adjusted to different lengths by operating a motor in the satellite.

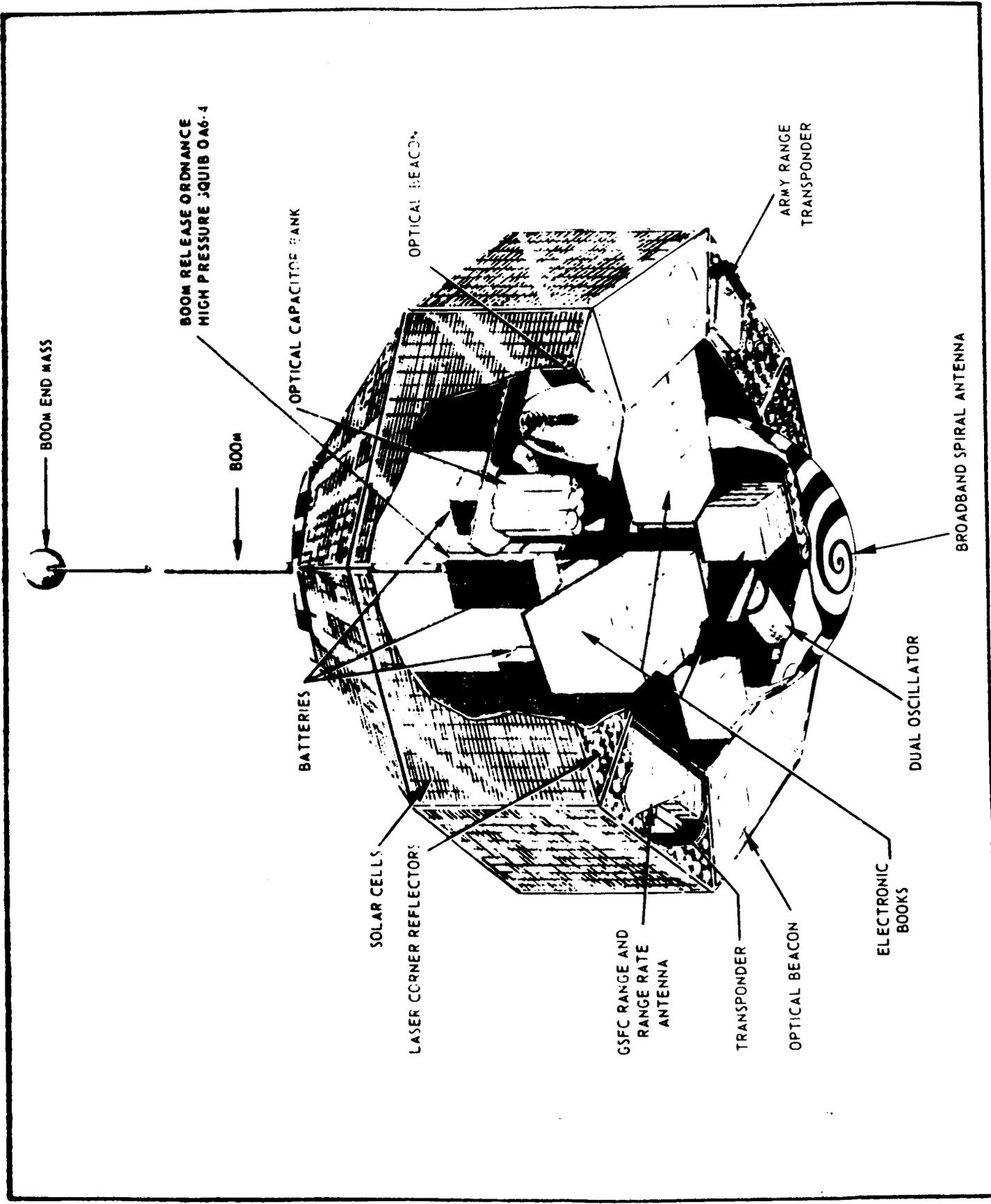
In addition to the equipment for making geodetic measurements, the main structure contains the satellite clock, memory computer system, command system, telemetry system, and three independent power systems wired to their associated solar cell arrays.

Despin rods are mounted in the satellite for removing residual spin of the satellite before the stabilization boom is extended.

The surface of the satellite oriented toward Earth is rimmed with eight panels. On four of them are the flashing light assemblies of the optical beacon system. The other four are covered with silvered quartz corner reflectors for the laser measurements.

Between two of these panels is a 4-inch high conical antenna for the range and range-rate system.

From the center projects a 24-inch diameter fiberglass hemisphere on which is painted the broadband spiral antenna for the Doppler system, the range transponder, command receiver, and the telemetry system.



GEOS-A FACT SHEET

Launch: No earlier than Nov. 2, 1965

Apogee: 920 statute miles (1500 kilometers)

Perigee: 690 statute miles (1100 kilometers)

Inclination: 59 degrees to Equator

Orbital Period: 111.52 minutes

Lifetime: One year design minimum

Weight: 385 pounds

Main Structure: Octahedron topped by a truncated pyramid; 48 inches wide, 32 inches high.

Appendage: Extendable boom, 60 feet long; conical antenna, 4 inches high; broad-band spiral antenna painted on 24-inch diameter hemisphere.

Geodetic Instrumentation:

1. Optical beacon system
2. Radio Doppler beacon
3. Range transponder
4. Range/range-rate transponder
5. Laser corner reflectors

Command System: Dual command receiver, dual command logic, and power switching circuitry, providing 32 ON and 32 OFF commands.

**Clock and Memory:**

A crystal oscillator with frequency divider, synchronized to Universal Time, controls timing markers broadcast on 162 and 324 Mc Doppler frequencies and 136 Mc telemetry frequency, and, through the memory, controls the timing of optical beacon flashes. The memory is a special purpose computer with a capacity of 65 digital words of 21 bits each. It programs the flashing of the optical beacons and checks on the operation by counting the flashes that occur.

**Power Systems:**

Three independent solar cell and nickel cadmium battery power systems:

1. Main Power System:

2,304 N on P solar cells and one 12 ampere hour battery of 8 cells; voltage, 11 volts nominal; power, 16 to 20 watts.

2. Optical Power System:

1344 N on P solar cells and one 12 ampere hour battery of 11 cells; voltage, 15 volts nominal; power, 9 to 12 watts.

3. Transponder Power System:

Same as Optical Power System.

**Telemetry System:** Four basic units: (1) two 35-channel (PAM) commutators that modulate two subcarrier oscillators that, in turn, phase modulate the 136.83 megacycle telemetry transmitter, (2) two 8-channel pulse duration modulation (PDM) subcommutators, and (3) three 15-bit telltale registers, (4) telemetry time marker. The telemetry transmitter radiates 400 milliwatts at 136.83 mcs, transmitting time markers and telemetry functions on command.

**Despin System:** Yo-yo device and eddy current rods.

**Stabilization System:** Gravity-Gradient Stabilization:  
Extendable 60-foot boom with eddy current damper end mass.

**Attitude Sensors:**

1. three magnetometers
2. six solar cells calibrated to provide Sun-line data.

GEODETTIC INSTRUMENTATION

Optical Beacon System

Four recessed xenon or "electronic" flash tubes, each emitting a light of 1,580 candle-seconds per flash will permit the satellite to be photographed against the stellar background.

Photographs made by cameras of the Smithsonian Astrophysical Observatory, the United States Air Force, the Coast and Geodetic Survey, the Minitrack Optical Tracking System and other facilities can be checked against stellar tables, including an SAO star map containing more than 260,000 stars measured to an accuracy of 1 second of arc.

By this means, scientists will be able to pinpoint the position of the satellite with great accuracy.

Four lights offer varying intensities and provide redundancy. They can be flashed simultaneously, in sequence, and individually.

The light flashes will be made in sequences of 5 or 7 with four-second intervals between flashes. The first flash will always occur at a precise Universal Time minute and to an accuracy of 0.4 millisecond relative to the National Bureau of Standards station WWV which broadcasts time and frequency standards.

Because the flashes can be programmed in the satellite memory, and triggered by its frequency divider mechanism, or clock, observers around the Earth can select future times at which they would like a sequence flashed and the number of lamps to be used.

At the time specified the memory will generate a sequence start command and send it to the optical beacon for execution. The memory has a capacity of 59 sequences, and a cycle time of 68 hours. It is expected that a new set of light flash requests will be injected into the memory every day.

The flashing light system was first employed in the ANNA I-B built by APL and orbited Oct. 31, 1962.

#### Laser Corner Reflectors

Quartz-cube corner reflectors, or prisms, on the satellite will be used for optically measuring the satellite range and angle.

The 322 cubes, mounted on fiberglass panels, will reflect pulsed beams of light directed at the satellite by ground laser transmitters when the satellite is within range. Reflected light can be picked up by a ground telescope and amplified by a photomultiplier tube that converts the optical impulses to an electrical signal. A digital counter will record the time at which the beam of light is returned to the ground.

Another system photographs the reflected laser pulse against the stellar background.

Total travel time of the light pulses, from ground to satellite and back to the ground, is a measure of the distance to the satellite and thus forms the basis of the satellite optical laser tracking system being developed by NASA Goddard Space Flight Center.

These time measurements, coupled with camera-obtained angular data, will precisely locate orbiting spacecraft and are expected to provide a very accurate method of tracking satellites.

Cube corner prisms are mounted on four of the eight flat panels on the bottom rim of the spacecraft. These prisms form the retro-reflectors used for the optical laser range and angle measurements.

Each prism is made of fused quartz with silvered reflecting surfaces. The 322 prisms on the spacecraft provide a total reflecting area of 0.18 square meters, about 280 square inches.

The corner reflectors conserve the narrow beamwidth of the in-coming light to provide maximum signal at the ground. The laser beam is returned almost exactly to where it originated. Fifty per cent of the light striking the prism area at a 90 degree angle will be reflected within a beam of 20 arc seconds.

Two other NASA spacecraft, Explorer XXII and XXVII, carry corner reflectors and are being used with success in the evaluation of laser techniques in deriving orbital and geodetic information.

Both Goddard and AFCRL will operate laser stations for GEOS.

#### Radio Doppler System

The Doppler beacon transmitter system on GEOS-A is an adaptation of equipment being used in the Navy's navigational satellites. It has been used for geodetic research in early Navy satellites, in the ANNA 1B, and more recently in NASA Explorer XXVII.

The Navy Doppler Tracking Network (TRANET) will be used to provide data for reduction and analysis by the Bureau of Naval Weapons that will help establish the structure of the Earth's gravitational field to an accuracy of about five parts in 100 million. The Navy has 15 permanent Doppler tracking stations.

The Doppler technique involves timing and measuring the frequency shift of radio transmissions from the moving satellite as observed by ground-based receivers.

Instrumentation consists of three transmitters operating on frequencies of 162 and 324 and 972 megacycles. The frequencies are generated by either of two stable oscillators.

The 162 and 324 Mc transmitters carry timing markers, bursts of 60-degree phase modulation, of about 0.3 second duration once per minute. The markers are synchronized with National Bureau of Standards Station WWV to an accuracy of 0.4 milliseconds or better.

Using the analogy of a train whistle effect, the Doppler shift, or change in radio frequency or pitch, is like the shift in the pitch of the whistle sound of a speeding train relative to the stationary hearer. Size of the shift, depends on how fast the train is going, how far the listener is from the whistle, and where the train is along the track

From a sufficient body of Doppler measurements, the orbit of the satellite can be computed. Conversely, with the orbit determined the Doppler data can be used to compute the location of the receiving station.

Irregularities in the Earth's shape, however, cause the satellite orbit to change slightly from a perfectly smooth elliptical orbit. The Doppler signals reflect these irregularities in the orbit, and the analysis of them provides a better picture of the size and the shape of the Earth, or geoid.

#### Range and Range-Rate System

The NASA Range and Range-Rate (R&RR) system was developed by the Goddard Space Flight Center and has the capability of determining with a high degree of accuracy both the range and the radial velocity of spacecraft traveling in near-Earth orbits or out to lunar distances.

An 8-pound R&RR system will be carried on the GEOS-A. Information obtained will augment other geodetic data and provide a comparison of the R&RR system with others used simultaneously in the spacecraft tracking.

The Goddard center will operate a network of R&RR stations in support of the GEOS project.

The on-board equipment consists of a transponder and a four-inch conical antenna.

The transmitter receives on a frequency of 2,270 Mc and transmits on 1,705 Mc with a power of 0.4 watts. The small antenna is used both to receive and transmit. It has a beam width of 150 degrees and is mounted on the Earth-facing portion of the spacecraft.

Range determination is essentially a time measurement. A carrier signal is modulated with several related frequencies and transmitted from the ground to the S-band transponder in the satellite. The transponder retransmits a slightly altered signal to the ground station. A phase comparison between the signal sent and the one received at the ground provides the range determination.

The range-rate is obtained by measuring the Doppler shift of the signal transmitted by the spacecraft--the time required to count a fixed number of cycles of the frequency.

#### Radio Range System

The radio range system on the GEOS-A is an incorporation of the SECOR (Sequential Collation of Range) system of satellites and ground stations developed for the Army Corps of Engineers. The SECOR ground stations are operated by the Engineer Corps' Army Map Service.

Key piece of equipment is the 8-pound satellite-borne transponder which receives and retransmits ground radio signals sent in sequence from four land-based stations. Basic ground elements include phase-modulated transmitters, range-data receivers, and electronic phasemeters.

The system is used to determine satellite and ground station positions by geometric means, proceeding step by step to extend the precision surveying around the globe. This will help establish intercontinental, interdatum, and interisland ties.

Station-to-satellite range is measured by observing the total phase shift of an accurately known modulation frequency. The shift in phase is proportional to distance and so provides a measurement of range in wavelengths of the modulated frequency.

Geodetic measurements are accomplished by sequential interrogation of the satellite, via the transponder, by four identical ground stations. Three of the stations are in known position; the fourth's location is to be determined.

Calculation of the dimensions of the triangles formed by the three ground stations of known position reveals the satellite's position. This is used with ranges from the unknown station to yield that station's geodetic location.

This station then is used as one of the three known stations and a new, fourth, unknown station is established. Thus, the survey work can leap-frog with all surveys eventually tied to one common base.

One of the stations, the "master" station, provides timing modulation on the signal it transmits to the satellite. This timing signal is retransmitted by the satellite transponder and received at the three "slave" stations, thereby establishing a time correlation among all four stations. This is used to specify the order in which each station should interrogate the transponder.

Each station, in turn, transmits a modulated signal to the satellite transponder, which detects the modulation and returns it on another signal to the ground station where the

transmitted and received modulation frequencies are phase compared to obtain an independent range measurement.

A sequence of four such interrogations, one from each station, is accomplished in 50 milliseconds, and these sequences can be repeated at a rate of 20 a second throughout the time interval selected for observation.

The satellite trajectory is then obtained by collating range measurements made from the three known locations. The most accurate results are obtained when the satellite is visible simultaneously at all four stations. The accuracy of range measurement is about 10 to 30 meters (33 to 100 feet).

The satellite transponder returns the ground signals on two different reply carriers. A receiver in the transponder removes the frequency modulated (FM) ranging frequencies from the interrogating carrier, generates two coherent reply carriers having an exact 2-to-1 frequency ratio 224.5 and 449 Mc and modulates both with the original FM ranging frequency. Other operating frequencies are: interrogating carrier, 420.9 Mc and FM ranging modulation, 548.937, 549.223, 583.246, and 585.533 kilocycles. Power output of the satellite transmitter is one watt.

The Army Map Service has 10 SECOR ground stations with six of them mobile. Additional stations are planned.

IMPORTANCE OF SIMULTANEOUS OPERATION

The tracking and geodetic measurement systems described in the preceding sections share a high degree of accuracy in making range, range-rate, and angular measurements.

Precisely how accurate they are in tracking satellites has been difficult to pin down because these systems have not simultaneously tracked the same satellites using the same coordinate system.

Procedures to date, of refining data to fit orbits and looking for irregularities, have uncovered short-term variations in tracking data but not the long-term or bias variations that may be the most significant.

The GEOS satellite will provide for the first time the means to detect and statistically specify anticipated long-term variations in tracking data.

This will be accomplished by using all the systems to track the spacecraft simultaneously on at least 100 passes over the East Coast of the United States.

Initially, the highly accurate short-arc orbit of the spacecraft, determined from camera data (photos of the flashing light against the star background), will serve as the reference orbit with which to compare tracking data from all other systems.

Enough redundant data should be obtained to make significant statistical inferences regarding certain features in the error models of the different systems.

SATELLITE CLOCK AND MEMORY

The satellite clock, based on extremely precise oscillations of the ultra-stable crystal oscillator of the radio Doppler system, will be used to trigger ~~the~~ optical beacon flashes and to control timing markers broadcast from the satellite.

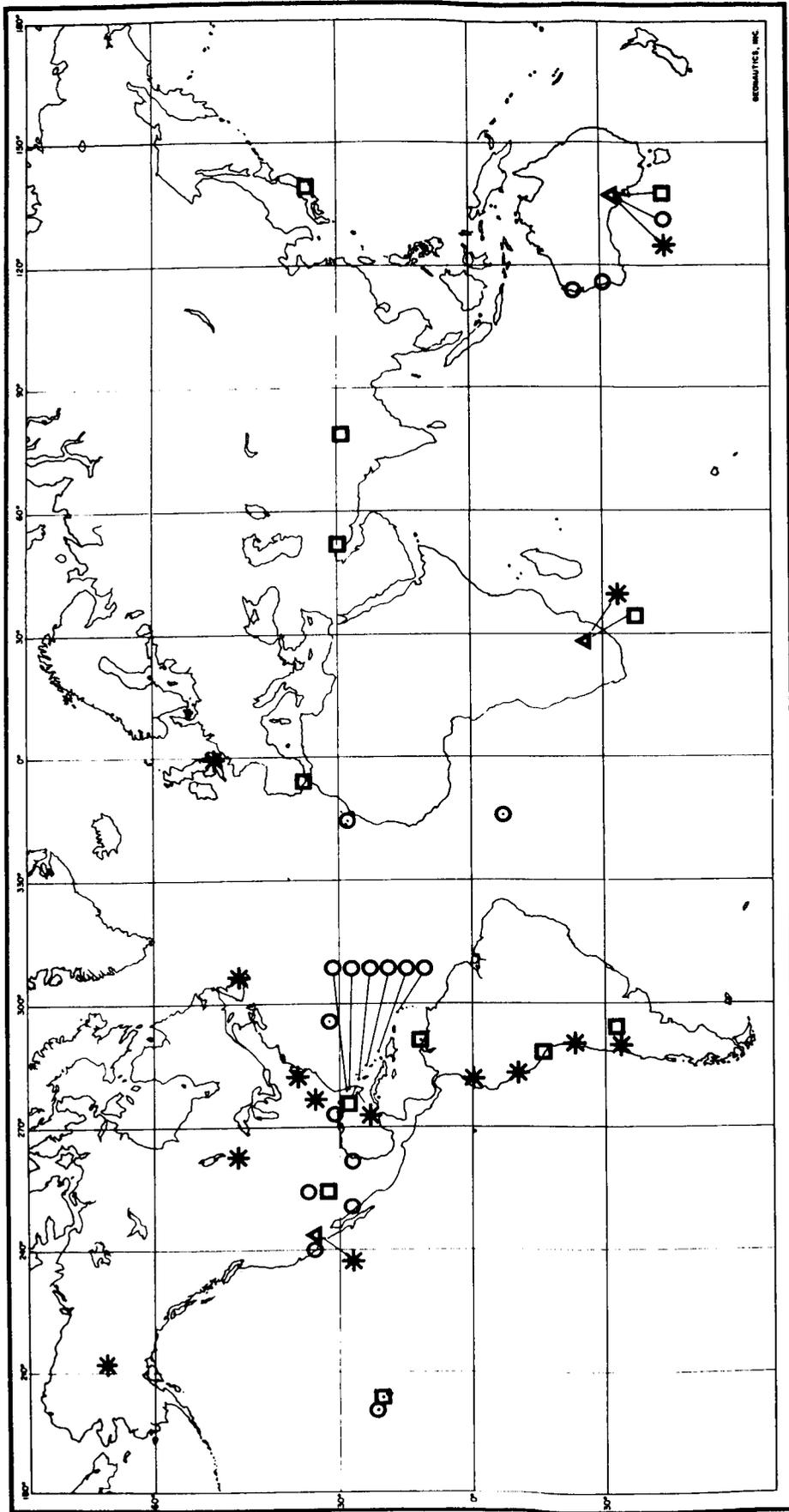
A frequency divider, the clock functionally divides the oscillator frequency by a ratio which can be adjusted over a total range of 38.6 parts per million. This ratio will be set by ground command.

The clock will be maintained in synchronism with Station WWV (National Bureau of Standards).

Timing markers broadcast on the 162 Mc and 324 Mc Doppler frequencies and the 136 Mc telemetry frequency, and the first light flash of each optical beacon sequence always will be emitted from the satellite on a precise Universal Time minute.

The memory will have a capacity of 59 flash sequences. The APL scientists who designed the clock estimate it will be possible to keep the satellite clock in synchronism with WWV at all times to within plus or minus 400 microseconds (one 400\* thousandths of a second).

The satellite memory is a fixed program, special purpose digital computer consisting of a 1,365-bit magnetic memory with timing and processing control circuits.



## NASA TRACKING FACILITIES

- — MANNED SPACE FLIGHT NETWORK
- ★ — SATELLITE TRACKING AND DATA ACQUISITION NETWORK
- ▲ — DEEP SPACE INSTRUMENTATION FACILITIES
- — OPTICAL TRACKING NETWORK

The 1,365 serial data bits are treated as 65 digital words of 21 bits each. These bits are assigned different functions and are used to execute the message injected into the memory.

Messages are coded according to the bit assignments so that the flash sequence will be initiated at the desired time, the requested number of beacons will flash, and the clock rate can be set.

The bits stored in the memory can initiate up to 59 flash sequences in any period up to a maximum of 68 hours. The entire memory contents are serially read out, processed, and restored once per minute. Flashes within sequences occur at four-second intervals.

Of the 65 memory words 59 can be used as flash sequence initiators. Provision is also made for tailoring the intensity and duration of each flash sequence to the needs of the users.

Word 60 provides for fine adjustment to the satellite clock rate, word 61 accumulates the total number of light flashes generated since the last memory load, words 62 to 65 provide the "barker word", a permanently wired format serving to mark the beginning of each memory scan at one minute intervals.

POWER SUPPLY

Primary source of power for operating the GEOS-A instrumentation and transmitters will be 4,992 N on P type silicon solar cells arranged in 16 panels on the side surfaces.

Shielding from radiation will be provided by an 0.02 inch thick fused silica cover slide with a blue reflecting optical filter.

Three independent power supplies, each with its own bank of solar cells and nickel cadmium battery, are used to operate the GEOS instrumentation. They are (1) the main power supply, which supplies power to the radio Doppler and telemetry systems, (2) the optical beacon flashing light power supply, and (3) the transponder power supply, which supplies power to both the radio range (SECOR) and the radio Range and Range-Rate systems.

This power isolation will reduce risk of damage to one section by possible failure of another and will minimize possible electrical interference between the various instruments.

Each storage battery is made up of 12 ampere-hour rectangular nickel-cadmium cells.

For added protection against catastrophic failures, the main power system will have a "solar only" mode. In such an arrangement, batteries can be by-passed and the instruments can be operated directly from solar cell energy.

In the event of the failure of the main power supply the satellite command system will automatically shift to the next operational supply.

### GRAVITY STABILIZATION SYSTEM

Critical to optimum use of the radio and optical beacons on GEOS-A is the gravity-gradient attitude stabilization system to keep the satellite antennas, laser reflectors, and optical beacons pointing earthward at all time.

This passive system, eliminating the need for powered attitude-control devices, has been successfully used in several satellites.

Gravity-gradient attitude stabilization uses the Earth's gravitational effect (gradient) to keep the satellite properly aligned with respect to the Earth. This is based on the tendency of an Earth-orbiting object with two concentrations of mass a distance apart to keep one end of the axis connecting them pointing toward the center of the Earth.

The differing pull of gravity between the two connected mass points, although very small, tends to stabilize their oscillations about the total object's center of mass and along the axis between the two. The GEOS mass points consist of the main eight-sided structure and a small mass at the end of the 60-foot boom.

The same principle keeps one side of the Moon pointing toward Earth at all times, apparently because the Moon's mass

on the Earth-facing side is markedly different than that of the opposite side. The Moon still oscillates slightly, turning from side to side and permitting Earth observers to see about 57 per cent of its surface over the years, but only 50 per cent at one time.

The attitude of the GEOS spacecraft will be detected by two systems.

One uses six solar cells, calibrated to give directional data from analog voltage output, for measuring the attitude of the spacecraft relative to the Sun-line. They also will provide information on the spin rate.

The second system consists of three flux-gate magnetometers used to determine the spacecraft's orientation relative to the line's of force in the Earth's magnetic field.

The two systems combine to define completely the spacecraft's attitude in orbit.

Two or three days after the satellite is in orbit attitude control will be initiated by erection of the 60-foot, silver-plated, beryllium-copper boom from its housing in the top of the pyramid section of the spacecraft.

Proper timing is important. When telemetered data from the solar attitude detectors and vector magnetometers indicate the desired end of the spacecraft is facing the Earth, APL's Howard County station will send the command for boom extension.

A copper-encased magnet at the end of the boom will remove oscillations from the boom and the satellite by transforming the oscillation energy first into eddy electrical currents and then into heat which will be dissipated in space.

The pull of gravity along the axis of the 60-foot boom and satellite, although only slightly different from one mass point to the other, is sufficient to keep one face of the satellite pointing earthward forever.

The assembly is motorized so that the boom can be extended or retracted to different lengths on command. Thus the attempt to stabilize can be repeated if not successful the first time.

The spacecraft is expected to be settled in the gravity-gradient stabilization mode by the end of the first week after launch, permitting the initiation of visibility predictions to the tracking networks.

PRINCIPAL INVESTIGATORS

The individual responsibilities of the scientific investigators differ somewhat. However, all will cooperate and assist in compiling their results for a handbook that will accumulate findings of the United States Geodetic Satellite Program.

This handbook will include (1) a mathematical analysis of the Earth's gravitational field as seen from satellite altitudes, (2) a map of the Earth that interrelates various geodetic reference points, placing these datums and isolated points on a standard coordinate system and (3) a discussion of the several observing techniques and an intercomparison of their effectiveness and accuracy.

The eight principal investigators for the geodetic satellite program are as follows:

Dr. Ivan I. Mueller, Ohio State University, Columbus, who will geometrically analyze observational data to locate observation points in a three dimensional, center of-the Earth coordinate system within 10 meters of accuracy.

Dr. Charles Lundquist (acting), Smithsonian Astrophysical Observatory, Cambridge, Mass., who will conduct satellite observations to (1) obtain a better representation of gravitational potential, (2) improve knowledge of the positions of the 12 SAO

Baker-Nunn camera stations, (3) determine the relations between various geodetic datums, and (4) intercompare observation techniques.

William M. Kaula, University of California, Los Angeles, Space Science Center, Institute of Geophysics and Planetary Physics, who will analyze camera, Doppler, and Range and Range-Rate observations to determine the Earth's gravitational field.

John H. Berbert, NASA Goddard Space Flight Center, Greenbelt, Md., who will acquire the appropriate observations and perform the necessary reduction and analysis of data to detect and statistically specify the accuracy of the several tracking systems employed.

Commander C. J. Limerick, Bureau of Naval Weapons, who will acquire, reduce, and analyze Doppler data to establish the structure of the Earth gravitational potential to an accuracy approaching five parts in 100 million.

John S. McCall, U.S. Army, Office of Chief of Engineers, who will perform and use radio ranging observations to accomplish intercontinental, interdatum, and interisland geodetic ties and to provide a calibration scale for the triangulation network.

Owen W. Williams, Air Force Cambridge Research Laboratory, Cambridge, Mass., who will obtain and use observations of the optical beacon flash sequences to pinpoint major world geodetic datums and observational sites with a three-dimensional uncertainty of 10 meters or less.

Capt. L. W. Swanson of the Coast and Geodetic Survey will use the later passive satellite (PAGEOS) primarily in obtaining observations and reducing and analyzing data to establish a worldwide geodetic net accurate to within about one part in 500,000 and trying together major known datums.

-more-

### THE DELTA LAUNCH VEHICLE

The GEOS-A will be the first spacecraft to be launched by NASA's Improved Delta, featuring enlarged second-stage fuel tanks.

The launch vehicle, including a thrust-augmented Thor first stage, the enlarged Delta second stage, and the X-258 third stage, is known as the Thrust-Augmented Improved Delta (TAID).

The Improved Delta permits placing bigger spacecraft in orbit at a small increase in cost. Performance is improved by increasing the burning time.

The earlier Deltas carried enough propellants in the second stage to burn for about 150 seconds while the Improved Delta will burn for about 400 seconds.

The 92-foot launch vehicle (including shroud) will leave Cape Kennedy's Complex 17, Pad A, and will perform a number of trajectory maneuvers prior to orbital injection of the spacecraft about 2,850 miles southeast of the Cape.

Orbital elements (nominal) for the GEOS-A mission include an apogee of 922 miles (statute), a perigee of 690 miles, an orbital period of 112 minutes and an inclination to the equator of 59 degrees. Injection velocity is 16,516 miles per hour.

The Delta launch vehicle project is under technical management of the Goddard Space Flight Center, Greenbelt, Md. Douglas Aircraft Co., is the prime contractor.

#### Delta Statistics

The three-stage Delta for the GEOS-A mission has the following characteristics:

Height: 92 feet (includes shroud)

Maximum Diameter: 8 feet (without attached solids)

Lift-off Weight: about 75 tons

Lift-off Thrust: 333,550 pounds (including strap-on solids)

First Stage (liquid only): Modified Air Force Thor, produced by Douglas Aircraft Co., engines produced by Rocketdyne Division of North American Aviation.

**Diameter:** 8 feet

Height: 51 feet

Propellants: RP-1 kerosene is used as the fuel and liquid oxygen (LOX) is utilized as the oxidizer.

Thrust: 172,000 pounds

**Burning Time:** About 2 minutes and 29 seconds

Weight: Approximately 53 tons

Strap-on Solids: Three solid propellant Sergeant rockets produced by the Thiokol Chemical Corp.

Diameter: 31 inches  
Height: 19.8 feet  
Weight: 27,510 pounds (9,170 each)  
Thrust: 161,550 pounds (53,850 each)  
Burning Time: 43 seconds

Second Stage: Produced by the Douglas Aircraft Co.,  
utilizing the Aerojet General Corp.  
AS110-118 propulsion system; major  
contractors for the auto-pilot include  
Minneapolis-Honeywell, Inc., Texas  
Instruments, Inc., and Electrosolids Corp.

Propellants: Liquid--Unsymmetrical Dimethyl Hydrazine  
(UDMH) for the fuel and Inhibited Red  
Fuming Nitric Acid for the oxidizer.

Diameter: 4.7 feet (compared to 2.7 feet for the earlier  
Deltas)

Height: 16 feet

Weight: 6½ tons (compared to 2½ tons for the earlier  
Deltas)

Thrust: about 7,800 pounds

Burning Time: 400 seconds (compared to 150 seconds for  
the earlier deltas)

Guidance: Western Electric Co.

Third Stage: Allegany Ballistics Laboratory X-258 motor.

Propellants: Solids

Height: 3 feet

Diameter: 1½ feet

Weight: 570 pounds

Thrust: 5,760 pounds

Burning Time: 22.5 seconds

- more -

Thrust-Augmented Improved Delta Flight Events (nominal) For GEOS-A Mission

<u>EVENT</u>	<u>TIME</u>	<u>ALTITUDE</u> ( <u>STATUTE MILES</u> )	<u>SURFACE RANGE</u> ( <u>STATUTE MILES</u> )	<u>VELOCITY</u> MILES PER <u>HOURL</u>
Strap-on Solids Separation	70 sec.	17	9	2,607
Thor burnout	2 min. 29 sec.	74	87	9,183
2nd. stage ignition	2 min. 33 sec.	80	97	9,161
Shroud separation	2 min. 36 sec.	82	101	9,164
2nd. stage burnout	9 min. 2 sec.	412	1,044	14,247
3rd. stage ignition	18 min. 41 sec.	690	2,777	12,995
3rd. stage burnout	19 min. 3 sec.	690	2,849	16,516

- more -

Delta Growth (1960-1965)

<u>Delta Configuration</u>	<u>Earth Orbit (300 miles)</u>	<u>Escape</u>
DM19 (1960)	525 lbs.	70 lbs.
DSV-3A & 3B (1962) 3-foot longer second stage tanks	800 lbs. *	95 lbs.
DSV-3C (1963) X-258 motor replaced X-248 motor	800 lbs. *	115 lbs.
DSV-3D (1964) three solid strap-on solid motors added to Thor	800 lbs. *	145 lbs.
DSV-3E (1965) 2-foot larger diameter second stage	1,400 lbs.	220 lbs.

\* Structural limits of the second stage rule out a spacecraft weight of more than 800 pounds.

DELTA LAUNCH VEHICLE RECORD

<u>MISSION</u>	<u>RESULTS</u>	<u>LAUNCH</u>	<u>WEIGHT</u> (Pounds)
Echo	failed	May 13, 1960	132
Echo I	successful	August 12, 1960	200
TIROS II	successful	November 23, 1960	280
Explorer X (P-14)	successful	March 25, 1961	80
TIROS III	successful	July 12, 1961	280
Explorer XII (S-C)	successful	August 16, 1961	90
TIROS IV	successful	February 8, 1962	280
OSO-I	successful	March 7, 1962	500
Ariel-1 (UK-1)	successful	April 26, 1962	160
TIROS V	successful	June 19, 1962	300
Telstar I	successful	July 10, 1962	171
TIROS VI	successful	September 18, 1962	280
Explorer XIV (S-3A)	successful	October 2, 1962	89
Explorer XV (S-3B)	successful	October 27, 1962	98
Relay I	successful	December 13, 1962	172
Syncom I	successful	February 14, 1963	150
Explorer XVII	successful	April 2, 1963	150
Telstar II	successful	May 7, 1963	410
TIROS VII	successful	June 19, 1963	300
Syncom II	successful	July 26, 1963	150
Explorer XVIII (IMP-1)	successful	November 26, 1963	138
TIROS VIII	successful	December 21, 1963	265
Relay II	successful	January 21, 1964	261
S-66	failed	March 19, 1964	116
Syncom III	successful	August 19, 1964	145
Explorer XXI (IMP-2)	low orbit	October 3, 1964	135
EPE-D	successful	December 21, 1964	110
TIROS IX	successful	January 22, 1965	305
OSO II	successful	February 3, 1965	545
Early Bird	successful	April 6, 1965	145
IMP III	successful	May 29, 1965	136
TIROS X	successful	July 1, 1965	290
OSO-C	failed	August 25, 1965	620